ESD-TR-65-411 MTR-5

STUDIES OF DISPLAY SYMBOL LEGIBILITY

Part IX. The Effects of Resolution, Size, and Viewing Angle of Legibility

MAY 1966

D. Shurtleff
M. Marsetta
D. Showman

Prepared for

DEPUTY FOR ENGINEERING AND TECHNOLOGY
DECISION SCIENCES LABORATORY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

Project 7030
Prepared by
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FOREWORD

This report is one of a series describing symbol legibility for television display. Additional information on this topic may be found in the following reports: "Studies of Display Symbol Legibility: The Effects of Line Construction, Exposure Time, and Stroke Width," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-249, February 1963; "Studies of Display Symbol Legibility, II: The Effects of the Ratio of Width of Inactive to Active Elements Within a TV Scan Line and the Scan Pattern Used in Symbol Construction," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-440, July 1963; "Studies of Display Symbol Legibility, III: Line Scan Orientation Effects," by B. Botha, D. Shurtleff, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-138, May 1966; "Studies of Display Symbol Legibility, IV: The Effects of Brightness, Letter Spacing, Symbol Background Relation, and Surround Brightness on the Legibility of Capital Letters," By D. Shurtleff, B. Botha, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-134, May 1966; "Studies of Display Symbol Legibility, V: The Effects of Television Transmission on the Legibility of the Common Five-Letter Words," by G. Kosmider, The MITRE Corp., Bedford, Mass., ESD-TR-65-135, May 1966; "Studies of Display Symbol Legibility, VI: Leroy and Courtney Symbols," by D. Shurtleff and D. Owen, The MITRE Corp., Bedford, Mass., ESD-TR-65-136, May 1966; "Studies of Display Symbol Legibility, VII: Comparison of Displays at 945- and 525-Line Resolutions," By D. Shurtleff and D. Owen, The MITRE Corp., Bedford, Mass., ESD-TR-65-137, May 1966; and "Studies of Display Symbol Legibility, VIII: Legibility of Common Five-Letter Words," by G. Kosmider, M. Young, and G. Kinney, The MITRE Corp., Bedford, Mass., ESD-TR-65-385, May 1966.

REVIEW AND APPROVAL

This Technical Report has been reviewed and is approved.

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ABSTRACT

An investigation was made to determine the visual sizes required for the identification of standard and revised Leroy alphanumerics, which were televised at resolutions of 10, 8, and 6 lines per symbol height. The visual size needed for 99 percent identification accuracy was similar for resolutions of 10 and 8 lines, but a significantly larger visual size was required for symbols resolved by 6 lines. There were no significant differences in visual sizes required for identification of standard versus revised Leroy symbols at any value of resolution. The findings were used to calculate the effective area for viewing televised symbols.

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SECTION I

INTRODUCTION

SYMBOL SIZE

This report describes a study whose purpose was to determine the visual size (angles in minutes of arc subtended at the eye by symbol height) required for good symbol identification with resolutions of 10, 8, and 6 active television scan lines per symbol height. Once the angles of subtense required for different values of symbol resolution are known, the usable viewing area for particular television displays can be determined.

In previous studies of symbol resolution,[1,2,3,4,5,6,7] a common visual size (angle of subtense) was used for the various values of resolution and the results showed, in all cases, that a significant increase in identification time occurred when symbol resolution was decreased from 10 to 8 lines, and from 8 to 6 lines. Errors of identification,[6] on the other hand, showed no significant differences between 10 and 8 lines, but did show a significant difference between 8 and 6 lines. On the basis of the previous data, then, one might expect that a larger angle of subtense will be required for good identification with a symbol resolution of 6 lines (and possibly with 8 lines) than will be required for a symbol resolution of 10 lines.

REVISED LEROY ALPHANUMERICS

Another purpose of the present study was to evaluate several revisions of the standard Leroy alphanumerics. It was hoped that changes in the geometry of some of these symbols might decrease the angle of subtense required for good identification, and thereby increase the usable viewing area

for televised symbols with a given value of resolution. The particular symbols revised were those which previous studies[6, 7] had shown to be confused frequently.

Only minor changes, e.g., lengthening or shortening strokes, were made in the symbols because slight modifications might assist identification, but would not, at the same time, require a major redesign of the standard Leroy lettering templates. For example, in an effort to reduce the "S called 5" confusion, the upper curve of the "S" was shortened and the upper bar of the "5" was lengthened (compare the new and old symbols in Figure 1). Both changes, as well as those made in other symbols, are possible with minor alterations of the standard Leroy lettering templates.

ALI3D4	3RL7CP	K5LWV9	M92PVO
JX3VM6	IVUKH4	6QSIDP	6X6NGQ
RTC9QG	TA4WIE	CWYØ5D	K8ØJB3
802ØRF	NSMBIY	Q9FHBT	72TAZB
EWHK7S	ZNMO24	OJ8ZX7	YEGFLS
5YZUAN	G5JXFØ	RPIU8E	UIDCIH

AL13D4	3RL7CP	k5LWV9	M92PVO
JX3VM6	IVUkH4	6QSIDP	6X6NGQ
RTC9QG	TA4WIE	CWYØ5D	k8ØJB3
802ØRF	NSMB1Y	Q9FHBT	72TAƵB
EWHk7S	ƵNMO24	OJ8ƵX7	YEGFLS
5YƵUAN	G5JXFØ	RP1U8E	U1DCIH

Figure 1. Symbol Arrays

SECTION II

METHODS AND PROCEDURES

SELECTION OF SUBJECTS

Twenty-four subjects were screened for 20/20 near and far acuity, normal color vision, and phoria on a Bausch and Lomb Ortho-Rater. The subjects were randomly assigned to one of six experimental conditions: one of the two lettering fonts and one of the three symbol resolutions (10, 8 or 6). Four subjects were used in each condition.

SYMBOL CONSTRUCTION

The symbols were arranged in a six-by-six array with a horizontal spacing between adjacent symbols of 25 percent of symbol height, and a spacing of 100 percent of symbol height between successive rows of symbols. The average width of the symbols was 3/4 of symbol height, and the stroke width was 1/6 of symbol height. There were four arrays for each lettering font with each symbol appearing four times in the set of four arrays. Figure 1 shows the eight arrays. At the top of the figure are shown the four arrays made up of Standard Leroy Alphanumerics, and at the bottom are the four arrays of the Revised Leroy Alphanumerics. The revised symbols are: B, G, H, K, Q, S, Z, 1, 5, 6, 7. The symbols were made up on 35 mm slides and backlighted by standard cool white fluorescent lamps which were arranged in a light box to provide uniform illumination over the array.

SYMBOL DISPLAY

The symbols were picked up by a General Precision television camera Model P/N 5358-6 (945 line) and displayed in the center of a raster of a Conrac 21" video monitor Model CQC (945 lines per frame). A more detailed description of the equipment is given in Shurtleff and Owen.[7] The brightness of the symbol scan lines was approximately 20 foot-lamberts and the brightness of the background (to one side of the symbol) was 2 foot-lamberts, which yielded a brightness contrast ratio of 10 to 1. The ambient illumination in the experimental room ranged from 6 to 8 foot-candles of standard cool white fluorescent light. The heights of the symbols on the television monitor were 0.200 inches for 10 lines, 0.160 inches for 8 lines, and 0.120 inches for 6 lines. The unused part of the monitor screen was obscured by a cardboard mask and the used portion of the screen was hooded to shield the display from ambient light.

DISTANCES BETWEEN MONITOR AND SUBJECT

A variation of the Method of Limits (a standard psychophysical technique) was used as a means of estimating the distance from the monitor at which a subject would have to sit in order to identify symbols with a given degree of accuracy. In the present study only a part of the technique was used in which the symbols were moved progressively nearer to the subject until he was able to make 95 percent correct identification. The initial placement of the array for each of the resolutions was determined before the start of the experiment by an observer who read the arrays at a number of distances. The distances at which he made approximately 50 percent errors were selected for the experiment. The distances were satisfactory for most of the subjects. The subject read a symbol array at the initial distance, and then the array was

moved six inches closer to the subject and he read the same array again. Subsequent trials consisted of moving the array progressively closer to the subject in increments of six inches until he was able to make 95 percent correct identifications. When reading the symbol arrays, the subject was seated at a table on which was mounted a head rest.

RECORDING SUBJECT'S PERFORMANCE

A pushbutton switch was used by the subject to turn on an array when he was ready to read the symbols, and a microphone and headset system relayed his responses to the experimenter who wrote them on a score sheet. The subject's identifications were also recorded on tape so that they could be played back to verify the written record. A standard electric timer was started automatically when the subject turned on a display, and was stopped by the experimenter after the subject had finished reading the array. The time to read the array was recorded in hundredths of seconds. The subjects were asked to identify the symbols as rapidly and accurately as possible. Each subject had two experimental sessions, each one lasting approximately 30 minutes. The subject read two of the four arrays during a session and was given a five minute rest period between reading the arrays.

SECTION III

RESULTS

DATA OBTAINED

Two sets of data were obtained from each subject: one set showed the accuracy of the subject in percent correct identifications for each of the distances used. Some illustrative examples of the data obtained for symbol resolutions of 10, 8, and 6 lines are shown in Figure 2. As to be expected, there was a gradual increase in accuracy as the monitor was moved closer to the subject. The second set of data shows the rate, in symbols per second, with which the subject was able to make identifications for each of the distances used. Some illustrated examples of the data are shown in Figure 3, where it is noted that the rate of symbol identification increased as the monitor was moved closer to the subject.

VIEWING DISTANCES ESTIMATED BY LOGIT ANALYSIS

For estimating viewing distances required for a given percentage of correct identifications, the accuracy data for each of the subjects (illustrative examples of these data are shown in Figure 2) were treated by a logic analysis.[8] In this analysis the proportions of correct (or incorrect) identifications are transformed into logits which are plotted against the logarithms of the distances. The logits are fitted by a straight line using the method of least squares. The parameters of the fitted line are used to determine the viewing distances of interest, in the present case the estimated distances at which 85 and 99 percent accuracy were attained. The 85-percent point was obtained for use in the statistical analyses of the data since it is a more

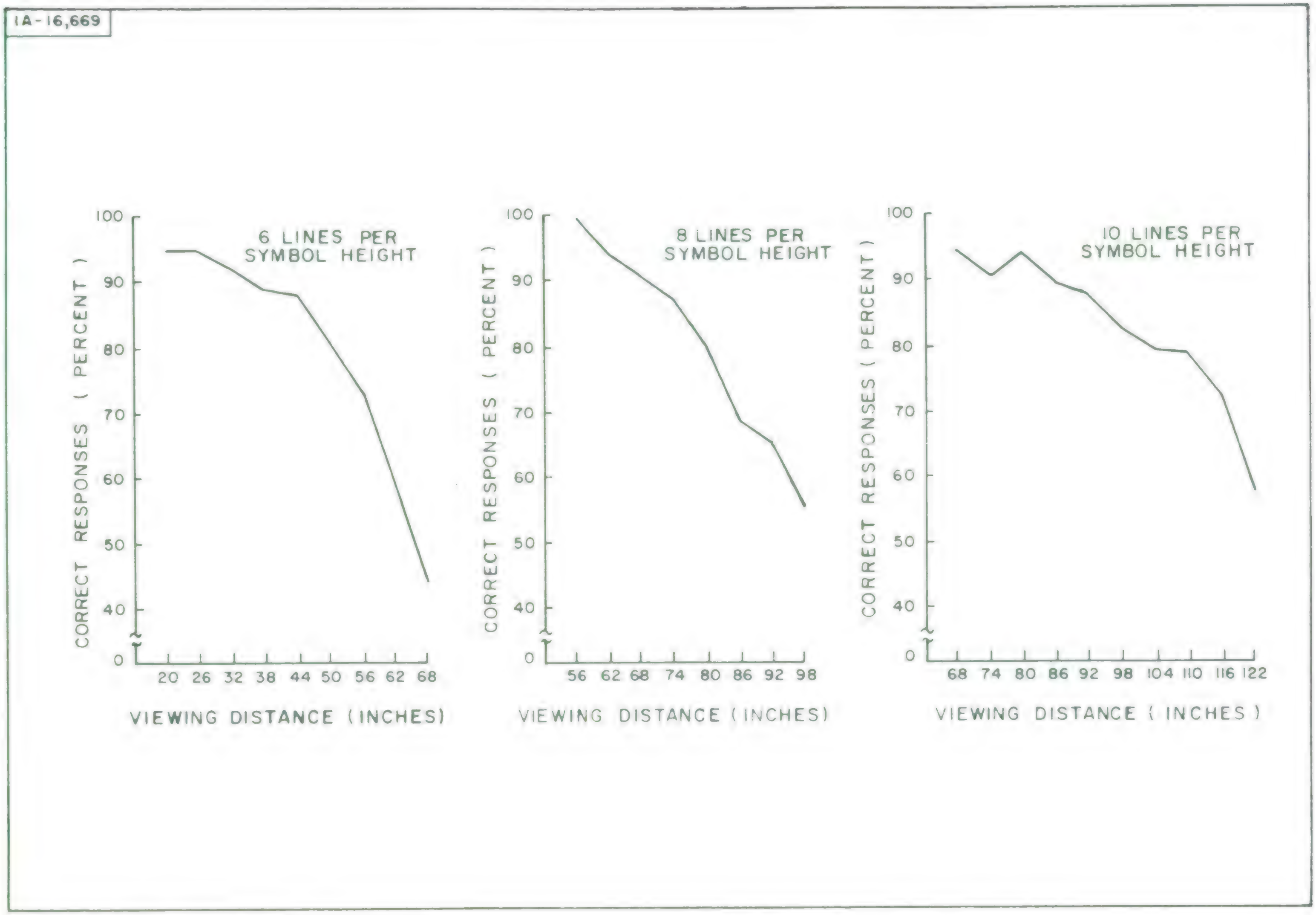

Figure 2. Percentage Accuracy for Several Viewing Distances

reliable (stable) estimate than the 99-percent point. The latter point was estimated because of its value in applied situations where error-free performance is desired. The particular computer program used for the logit analysis also yields a chi-square test of the goodness of fit of the straight line to the data. Only two of twenty-four logit functions showed a statistically significant deviation from a straight line.

VISUAL ANGLES SUBTENDED BY SYMBOL HEIGHT

The estimated distances obtained from the logit analysis at which 85 and 99 percent correct identifications occurred were used to calculate the visual angles subtended by symbol height. Table I shows the average angles, in minutes of arc, subtended at the eye by symbol height. Inspection of Table I shows that the angles of subtense were similar for the two fonts at each value of symbol resolution. The angles of subtense were similar also for symbol resolutions of 10 and 8 lines, but for a resolution of 6 lines, a larger angle is required, especially for 99 percent accuracy.

Analysis of Variance

The data of Table I were submitted to an analysis of variance, one for visual angles at the 85-percent point, and a second one for angles at the 99-percent point. Both analyses showed that symbol resolution was the only significant source of variance. The use of Duncan's procedure[9] for comparison of the different means showed that a symbol resolution of 6 lines differed significantly at the 0.01 level from both 8 and 10 lines, but that 8 and 10 lines did not differ significantly from each other.

Table I

Subtended Angles Required for 85 and 99 Percent Accuracy

Resolution In Lines Per Symbol Height	Leroy Symbols Standard		Leroy Symbols Revised	
	Identification Accuracy (Percent)		Identification Accuracy (Percent)	
	85% (minutes of arc)	99% (minutes of arc)	85% (minutes of arc)	99% (minutes of arc)
10	7.58	13.15	7.59	13.37
8	7.57	12.82	7.70	15.09
6	10.35	35.97	11.01	30.08

IDENTIFICATION RATES

For the purpose of estimating the rate at which subjects were able to identify symbols at the 85- and 99-percent points, the curves for each subject (illustrative examples of these data are shown in Figure 3) were fitted by the method of least squares by a second-degree polynomial function. A linear fit was also attempted by the same method, but the polynomial better approximated the obtained data points. The average rates, in symbols per second, are in Table II. These data indicate that rate scores were similar for symbol resolutions and for fonts at both the 85- and 99-percent threshold. The extremely slow rates for the group shown standard Leroy symbols with a resolution of 8 lines were caused, most likely, by the unfortunate chance assignment of three of the slowest subjects in the experiment to this one group. Aside from the group just described there are only minor differences among rate scores for the conditions studied.

Table II

Identification Rates at 85 and 99 Percent Accuracy

Resolution In Lines/Symbol Height	Leroy Symbols Standard: Identification Accuracy (Percent) 85 (symbols/sec)	Leroy Symbols Standard: Identification Accuracy (Percent) 99 (symbols/sec)	Leroy Symbols Revised: Identification Accuracy (Percent) 85 (symbols/sec)	Leroy Symbols Revised: Identification Accuracy (Percent) 99 (symbols/sec)
10	1.16	2.00	1.25	1.89
8	0.74	1.22	1.25	1.54
6	1.33	2.04	1.16	1.85

INTERSYMBOL CONFUSIONS

A confusion matrix was obtained for identifications at the 85-percent point to see how particular symbol confusions were affected by the geometric revisions of the Leroy symbols. Tables III and IV show the identification errors for the revised and standard Leroy symbols, respectively. As expected, the total error was nearly identical for the two fonts. The distribution of errors for both sets of symbols shows that:

1. The changes in the "Q," "S," "5," and "7" had little effect on the distribution of errors for these symbols. The "Q" was still called "O." The "S called 5" and the "5 called S" confusions were approximately the same for the revised and standard symbols.

2. The changes in the "K" and "1" were clearly unfortunate since the revisions increased the total errors for these symbols and, in the case of the "K," increased "K called R" and "K called A" errors. The revision of the "1" greatly increased the "1 called I" errors. Also, the new "Z" was a failure since an increase occurred in the "Z called 2" errors, although total errors for the two "Z's" were nearly equal.

3. The revised "G" increased the "G called 6" errors, but there was a large decrease in the "6 called G" confusion. Also, the revised "G" was given as an erroneous response only half as often as the standard "G." Consequently, the revised "G" must be viewed with mixed feelings.

4. The "H" and the "B" appear to be the only successful revisions. The new "H" had fewer errors than the standard "H," and the confusions with the "M" and "N" were eliminated. The new "B" was never called "8," but the revision made little change in the "8 called B" confusion.

Table III
Confusion Matrix Summed for Revised Leroy

Symbol Called

Symbol Shown

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	
A																																					Ø
B				4																																	4
C							6								1																						7
D															7																						7
E			1			1					1															1											4
F																				2							1										3
G				1											4		1														1	10				1	18
H									1																		1										2
I																				4						2	4	1	1								12
J																				1																	1
K	2							1										2						1								1					7
L																																					Ø
M														2							4		1														7
N																																					Ø
O			1	3													2															1				3	1Ø
P						1																															1
Q				1			5								11																	1				1	19
R		2						1						1		1																					5
S					1																										8						9
T																									1												1
U																																					Ø
V																									3												3
W																																					Ø
X											9																										9
Y																				1		3															4
Z																												4									4
1									20	1		2																									23
2																										3			1								4
3																			3												1						4
4																																2					2
5																			15																		15
6					1		1																														2
7																				2																	2
8		15		1										1	1				2													2				3	25
9				1															1																		2
Ø															1	2																					3
	2	17	2	11	2	2	12	2	21	1	1Ø	2	Ø	4	25	3	3	2	21	1Ø	4	3	1	1	4	6	6	5	2	Ø	1Ø	17	Ø	Ø	Ø	8	219

Table IV
Confusion Matrix Summed for Standard Leroy

Symbol Called (columns); Symbol Shown (rows)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	
A																																					Ø
B				2														1																4	1	2	10
C							8								3																						11
D															4		1																				5
E			2																																		2
F																									1								1				2
G				1											4																	6		2			13
H									2				3	3													3										11
I																			1							2											3
J																								1			2										3
K																		1																			1
L																																					Ø
M																							3														3
N				1				1					1																								3
O				7			2										3																	1		2	15
P																																					Ø
Q				3			2								12																				1		18
R	1												1			2																				1	5
S																															8					1	9
T																									1								1				2
U									1																												1
V																									3												3
W																																					Ø
X											7														1												8
Y																				1		2															3
Z																																					Ø
1								1	11	2		1		1							1																17
2																										6											6
3																			1												2						3
4																																					Ø
5																			9			1							1			1					12
6					3		13										1													2							19
7																				1																	1
8		12													1			1	1													1				5	21
9			1	1															1				1						2	1							7
Ø				1											1		1																				3
	1	12	3	16	3	Ø	25	2	14	2	7	1	5	4	25	2	6	3	13	2	1	3	4	1	6	8	5	Ø	3	3	10	8	2	7	2	11	220

SECTION IV

DISCUSSION OF RESULTS

ANGLE SUBTENDED BY SYMBOL HEIGHT

The results of the present study showed that a significantly larger angle of subtense is required for a symbol resolution of 6 lines than for symbol resolutions of 8 or 10 lines. This finding is in agreement with that of a previous study[6] in which a symbol resolution of 6 lines was found to produce poorer performance than a symbol resolution of 8 or 10 lines. Additional points of agreement between the present data and those of previous studies are apparent when rate and accuracy of symbol identification are determined for a common angle of subtense. Table V shows rate and accuracy of symbol identification (average for eight subjects) for resolutions of 6, 8, and 10 lines for an angle of subtense of nine minutes of arc. These findings support those of previous studies[6,7] which showed similar error scores for 8 and 10 lines, but an increase in errors for a resolution of 6 lines. Also, the data of earlier studies showed a progressive increase in symbol identification time as resolution was decreased from 10 to 6 lines, which suggests that rate of symbol identification also progressively decreases for these values of resolution; this prediction is supported by the data of Table V.

IDENTIFICATION RATES

An additional point of interest concerning the rate scores is that the subjects were not reading symbols at a maximum rate even when their identification accuracy reached 99 percent. Studies by Crook[10,11] indicate that, in a task like that of the present study, it is possible for subjects to identify from 3.0 to 3.3 symbols per second. However, in the present study the

highest rate of identification at the 99-percent accuracy point was approximately 2.0 symbols per second, or 33 to 39 percent less than the maximum. An estimate of the distance at which the subjects in the present study should reach a maximum rate of identification may be found by extrapolating their time data to closer viewing distances (examples of the time data are in Figure 3). These distances were estimated, and it was found that a visual angle of subtense of 22 to 25 minutes of arc would probably be needed before subjects could identify symbols at a maximum rate.

Table V

Data at Nine Minute Subtense Angle

Resolution (Lines/Symbol Height)	Identification Rate (Symbols/Sec)	Percent Errors
6	1.26	14
8	1.30	8
10	1.46	8

ANALYSIS OF CONFUSIONS

The analysis of specific confusions for the standard and revised Leroy indicated that, of the changes made, only those of the "H" and "B" were successful. It is possible that the minor changes in the details of the other symbols were not detected by the subjects because of the relatively coarse values of resolution used in the study. If so, the effects of these changes would appear only with values of resolution greater than 10 lines per symbol height. In any case, until further evaluation of these changes is made, there is little to be gained by use of the revised symbols, with the possible exception of the "H" and "B." Even though the results for most of the revised

symbols were negative, they serve to illustrate a point made earlier in the report; namely, that subjective impressions about what should aid identification are unreliable and for this reason need to be verified by the use of objective techniques.

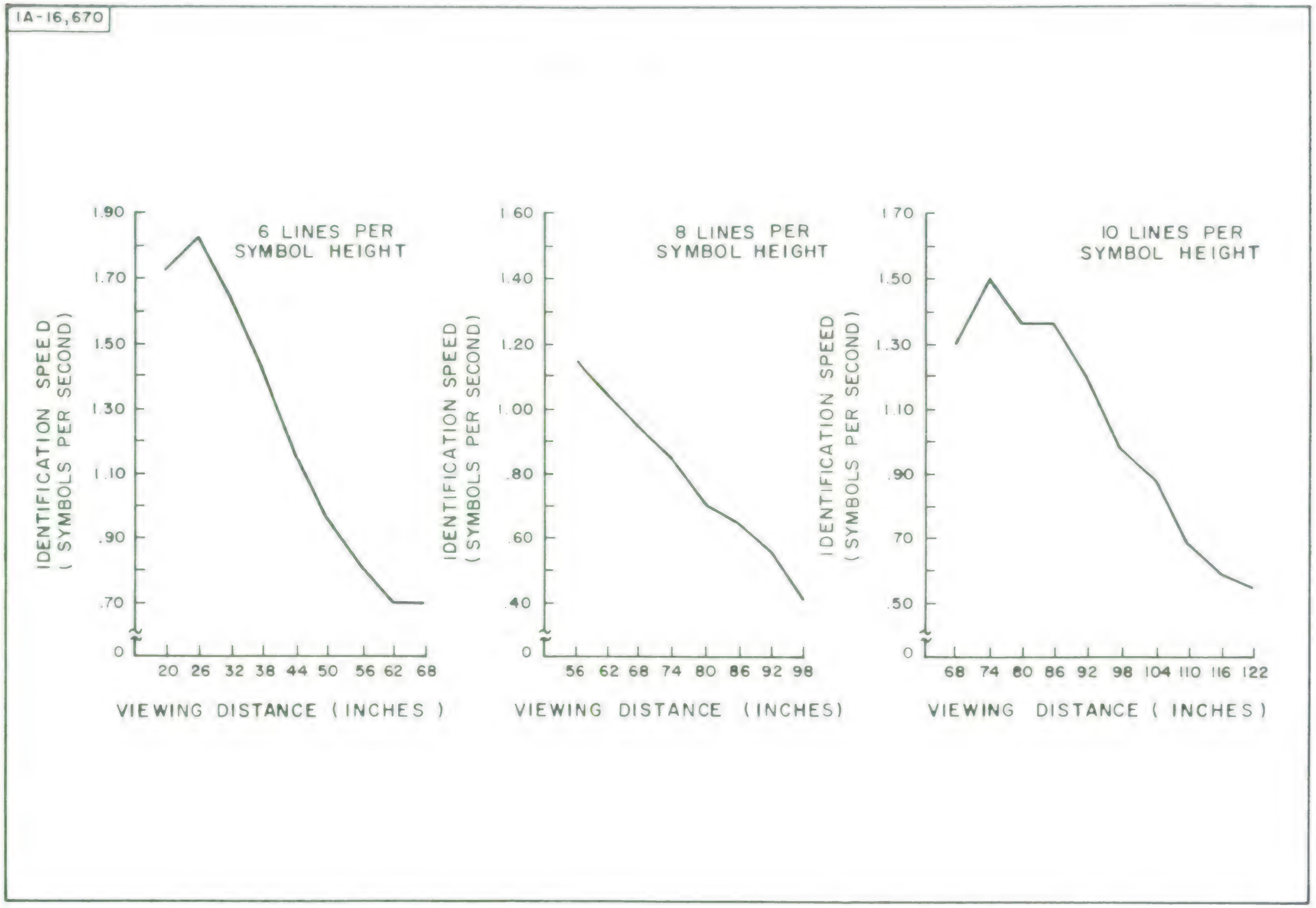

Figure 3. Identification Rates for Several Viewing Distances

SECTION V

SECOND PART OF EXPERIMENT

EDGE DISPLAY ON PICTURE TUBE

The purpose of the second part of the experiment was to determine the visual angles of subtense required for symbols displayed at the edge of the television raster (to the side of the tube center). In the first experiment the symbol arrays had been displayed only at the center of the raster (middle of the tube face). There was some question about how the results for the center apply to symbols displayed at other positions on the raster. Therefore, in order to obtain a reasonable estimate of the usable operator viewing area for symbols displayed at any position on the raster, it was necessary to determine if larger angles of subtense are required for symbols displayed at the edge of the TV raster. Larger angles of subtense were anticipated because of possible symbol defocussing at the edge of the raster (a common feature with TV monitors).

SUBJECTS SELECTED

Four subjects, who had been shown a symbol resolution of 10 lines in the main experiment, were rerun in the same manner as before with the exception that the symbol arrays were shown at the edge of the raster (extreme left center) instead of at the center. The subjects read the same symbol arrays that they read in the first experiment.

VISUAL ANGLES REQUIRED

The visual angles required for 85 and 99 percent identification accuracy of symbols displayed at the center and edge of the raster are in Table VI.

All four subjects required a larger angle of subtense for symbols displayed at the edge of the raster than they did for symbols displayed at the center of the raster. For 99 percent accuracy of identification of symbols displayed at the edge of the raster, the angle of subtense needs to be increased about 1.5 minutes (11 percent) over that required for the same accuracy when symbols are displayed at the center of the raster.

IDENTIFICATION RATE

The identification rate was better, in general, for symbols displayed at the edge of the raster than for symbols displayed at the center of the raster (see Table VI). Since the first part of the experiment showed that identification rates were not systematically related to either symbol resolution (at comparable values of accuracy) or symbol font, the better rate scores obtained for symbols displayed at the edge of the raster probably indicate the effects of practice in the reading of symbol arrays rather than the effects of the position of the symbol on the television raster, recalling, in this respect, that the same subjects were used in both the first and second parts of the experiment.

Table VI

Symbol Sizes and Rates for Center and Edge Displays

Subject	85 Percent Identification Accuracy Visual Angle (Minutes)		85 Percent Identification Accuracy Rate (Symbols/Sec)		99 Percent Identification Accuracy Visual Angle (Minutes)		99 Percent Identification Accuracy Rate (Symbols/Sec)	
	Raster Position		Raster Position		Raster Position		Raster Position	
	Center	Edge	Center	Edge	Center	Edge	Center	Edge
1	7.62	8.14	1.49	1.63	12.66	14.72	4.54*	2.17
2	6.90	7.14	1.28	1.59	11.86	12.31	1.26	2.50
3	8.10	8.41	1.06	1.33	15.14	17.31	1.33	1.41
4	7.34	7.39	1.20	1.54	11.07	12.16	1.92	2.44
MEAN	7.49	7.77	1.26	1.52	12.68	14.12	2.26	2.13

* The identification rate values were derived by mathematical extrapolation of obtained points; therefore, extreme values like this sometimes occur.

SECTION VI
THIRD PART OF EXPERIMENT

THE USEFUL VIEWING AREA

The most useful operator viewing area for applied situations is the area surrounding the monitor in which the operator can move about (or position himself) and still be able to identify symbols with a high degree of accuracy. Therefore, in the calculation of these areas for the present television equipment, it is desirable to use the estimated 99-percent points found in the first part of the experiment. However, there were two reasons for suspecting the validity of the 99-percent points estimated in the first part of the experiment. First, these points were obtained by extrapolation of the data points by use of a logit analysis, and there is reason to suspect that the logit analysis is not too reliable in estimating accuracy points beyond 95-percent. Secondly, the estimated 99-percent point is based upon a procedure in which the symbols are moved successively closer to the subject. Because of these repeated exposures of the symbol arrays at distances up to the one at which 99-percent accuracy is achieved, one might expect that the subject's performance at the 99-percent distance would be different from that obtained with just a single exposure of the arrays at this same distance.

SELECTION OF SUBJECTS

Four subjects, who had been shown a symbol resolution of 8 lines in the first experiment, were rerun in the same manner as before with the exception that the monitor was placed initially at the distance for which the logit analysis predicted 99-percent accuracy instead of at the distance for which

approximately 50-percent accuracy had occurred in the first part of the experiment. The subjects read the same symbol arrays that they read in the first experiment.

PREDICTED AND OBTAINED VIEWING DISTANCES

The estimated distances at which each of the subjects should be making 99-percent correct identification, according to logit analysis, and the distances at which they were in fact able to make 99-percent correct identifications are shown in Table VII. The data of the table indicate that the monitor had to be moved six inches closer than the distance estimated by the logit analysis before three of the four subjects were able to identify the symbols with 99-percent accuracy. No statistical analysis of these data was attempted because of the small number of subjects used. Furthermore, in the interest of making a conservative estimate of the usable operator viewing area for television displays, it was decided to reduce the estimated 99-percent points by six inches since three of the four subjects indicated the monitor had to be moved this much closer before 99-percent accuracy was obtained. The estimated and obtained rates of identification are also in Table VII, and indicate fairly good agreement between the estimated scores and those obtained from the four subjects.

CALCULATION OF USABLE VIEWING AREAS FOR TELEVISED SYMBOLS

The data of the first, second, and third parts of the experiment may be used to plot the appropriate operator viewing area for displays with symbol resolutions of 10 or 8 lines. Before these areas could be plotted, it was necessary also to find a means for estimating viewing distances for different angles of viewing since the present data provided estimates only of the viewing distances for displayed symbols normal to the line of sight (when the

line of sight, with the eyes looking straight ahead, is perpendicular to the display surface). Fortunately, an earlier study by Reinwald[12] showed how viewing distance varied for different angles of viewing.

Table VII

Predicted and Obtained Viewing Distances

Subject	99 Percent Identification Accuracy Viewing Distance (Inches)		Identification Rate (Symbols/Sec)	
	Predicted	Obtained	Predicted	Obtained
1	33.2	27.2	1.8	2.1
2	44.5	38.5	1.2	1.3
3	52.2	46.2	1.2	1.8
4	37.4	37.4	2.4	2.2
MEAN	41.8	37.3	1.6	1.8

Reinwald's Formula

Reinwald fitted his data with a cosine function and the distances required for viewing at different angles may be estimated by the formula, $D = b\ (\text{cosine}\ \theta)^{2/3}$, where D is distance in feet, b is the distance in feet required for 99-percent accuracy in identification of symbols displayed normal to the line of sight, and θ is the angle in degrees from the normal line of sight. Reinwald's formula was used in the present study to estimate the viewing distances for viewing angles of 75, 60, 45, 30, and 15 degrees.

Usable Areas

The usable areas for viewing television displays with symbol resolutions of 10 or 8 lines are plotted in Figure 4. The solid curves of the figure show

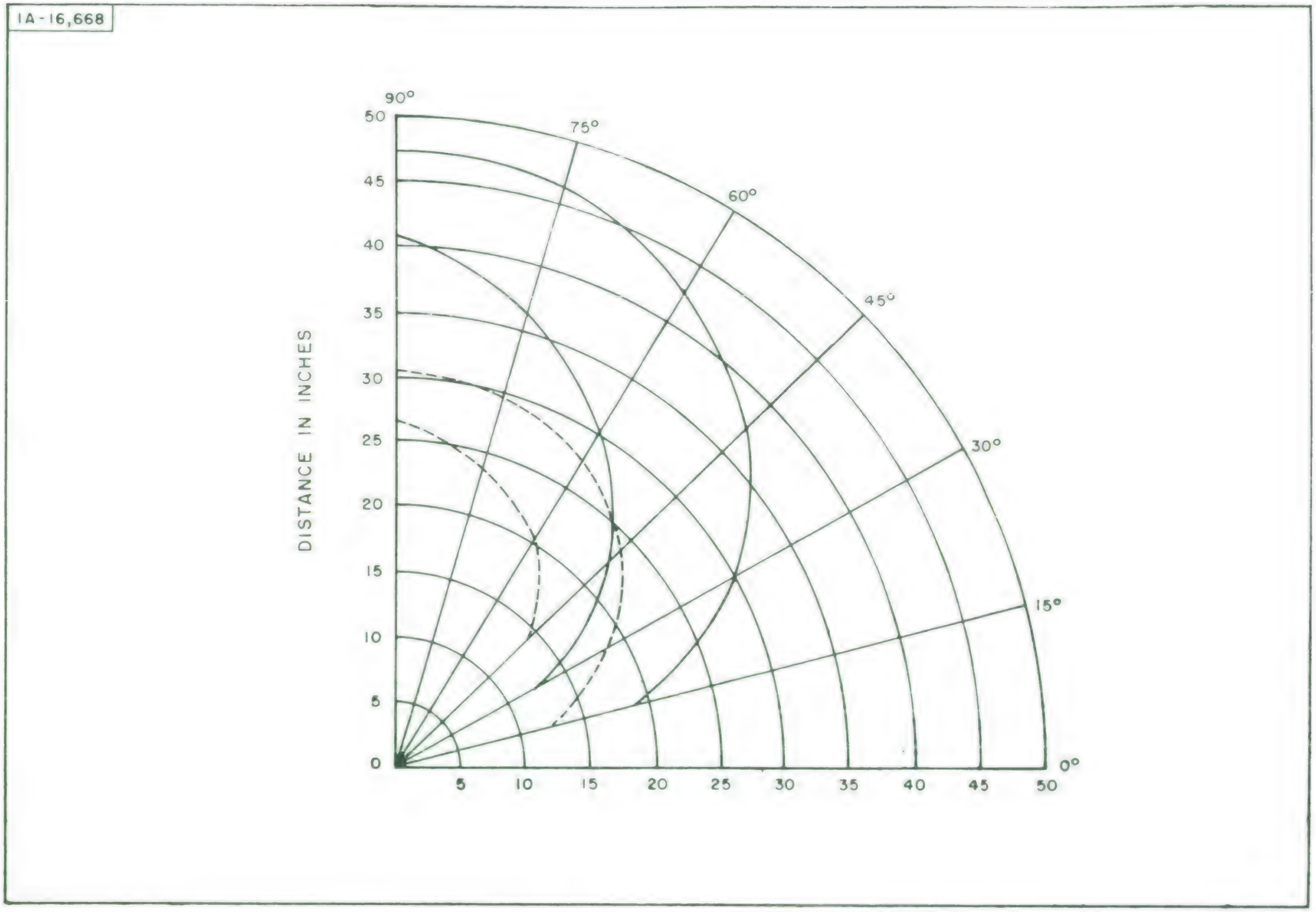

Figure 4. Usable Viewing Area for 99 Percent Accuracy

the estimated viewing distances (inches) from the monitor at which a subject with normal vision should be able to identify, with 99 percent accuracy or better, standard Leroy symbols resolved by 10 TV lines.

Center Display

The upper solid curve represents the usable viewing area when symbols are displayed only at the center of the raster. The distance on the 90-degree axis of the upper solid curve represents the average distance at which the subjects who saw a symbol resolution of 10 lines were estimated to make 99-percent correct identifications in the first part of the experiment. The average distance was reduced by six inches to correct for possible error of estimate of the 99-percent point in accordance with the finding of the third part of the experiment. The distances for viewing angles from 75 to 15 degrees were estimated using Reinwald's formula.

Center and Edge Display

The lower solid curve of Figure 4 is an estimate of the viewing area when symbols with a resolution of 10 lines are displayed at the edge of the raster as well as at its center. This curve represents the area of overlap obtained when the effective viewing area for symbols displayed at the center of the raster is plotted together with similar viewing areas for symbols displayed at the edge of the raster.

The extent of overlap was determined by plotting three separate curves on the same graph (Figure 5). One curve was the same as the upper solid curve of Figure 4 for symbols displayed at the center of the raster. The other two curves were plotted in the same way as the latter, but for symbols displayed at the edge of the raster instead of at its center, and are displaced to the left and right, accordingly. The distance required for 90-degree

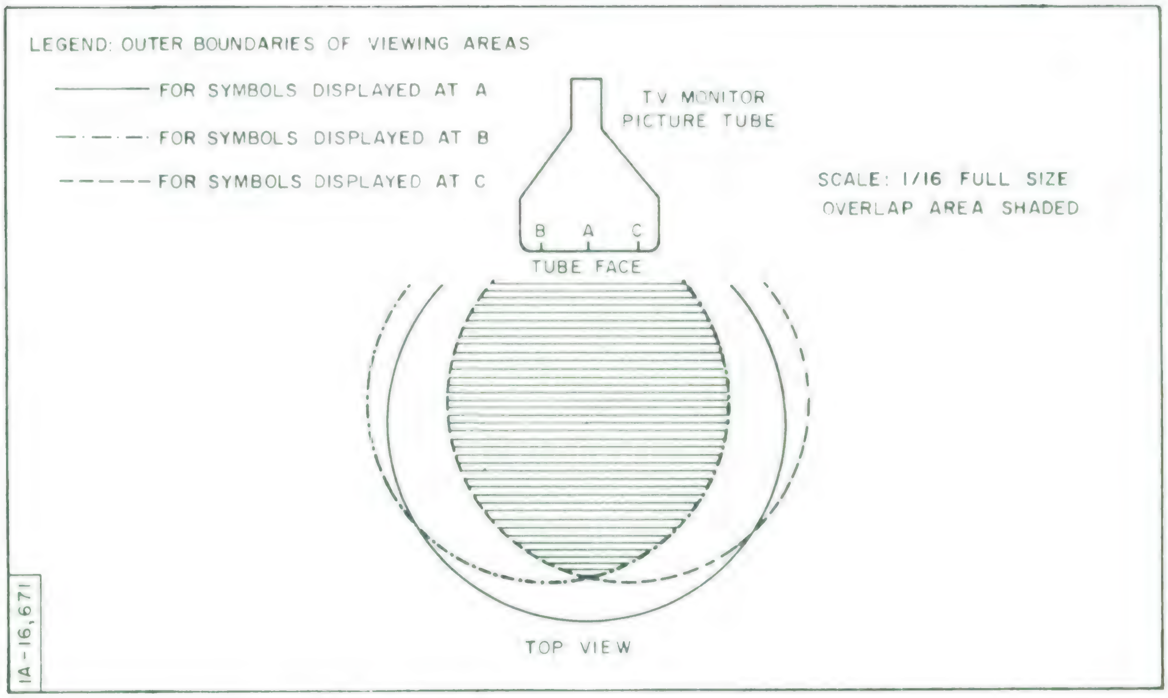

Figure 5. Viewing Area Overlap

viewing angle for the latter two curves was derived from the results of the second part of the experiment, which showed that the subject would have to sit slightly closer to the monitor in order to identify symbols at the edge of the raster with the same accuracy as when they are shown at the center of the raster.

The area overlapped by these three curves should approximate fairly well the usable viewing areas when the entire raster is used to display symbols. For example, when the entire raster is used, the subject can be placed up to 40 inches away from the monitor, along the normal line of sight (90 degree axis), and be expected to identify symbols with 99 percent accuracy or better. When the viewing angle is 45 degrees from the normal line of sight (45 degrees from the perpendicular to the tube center), the

subject needs to be positioned at a distance no more than 22.5 inches from the monitor in order to identify symbols with this same accuracy.

Viewing Areas for 8-Line Resolution

The broken curves of Figure 4 show the estimated viewing areas for a symbol resolution of 8 lines. Again, the top curve represents the area of viewing for symbols displayed only at the center of the raster, and the bottom curve is the estimated area of viewing when the entire raster is used to display symbols. Similar plots of areas of viewing for a symbol resolution of 6 lines were not attempted since the distance required for 99-percent accuracy on the 90-degree axis was less than the normal reading distance for adults (12 to 13 inches).

Printed and Photographed Symbols

While Figure 4 compares the usable area of viewing for different kinds of television displays, Figure 6 shows a comparison of viewing areas for symbols constructed with 10 television scan lines (shown at the center of the raster) versus printed or photographed symbols. The curve for the solid-stroke symbols is based upon data of two independent studies [13, 14] which showed that, under conditions comparable to those of the present television study, 99-percent accuracy should be attained with an angle of subtense of 9 minutes of arc for symbols displayed normal to the line of sight. Symbols 0.200 inches high, which is the size of the television symbols with a resolution of 10 lines, subtended approximately 9 minutes of arc at a distance of 76 inches. The distances required for the different viewing angles were estimated in the same manner as for the television symbols, namely, by use of Reinwald's equation. Figure 4 indicates that the usable area of viewing for the television display is approximately half the size of that for good quality solid-stroke symbols of the same size.

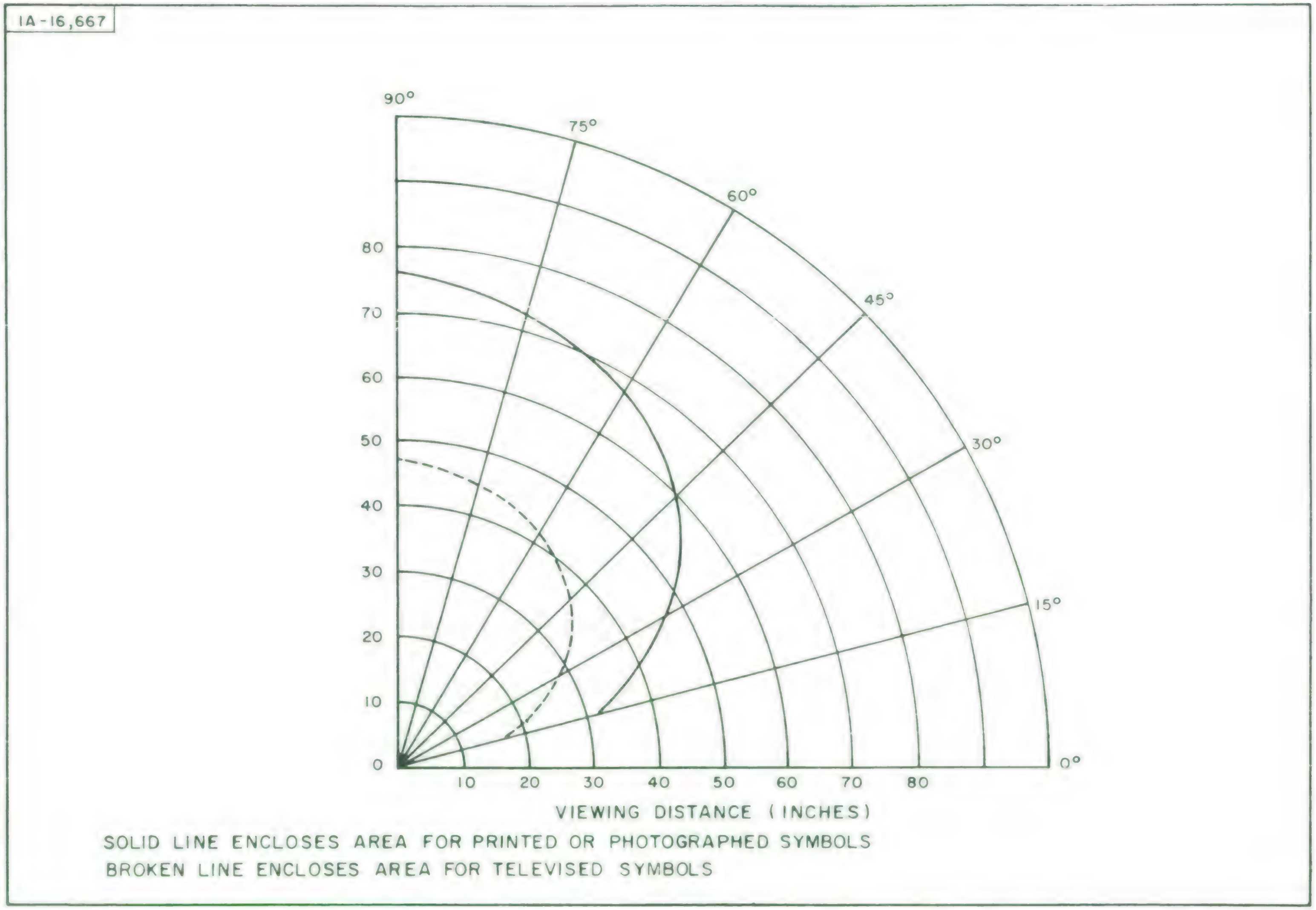

Figure 6. Usable Viewing Area for 99 Percent Correct Identification

Figure 7 shows the total, horizontal viewing area for good quality solid-stroke printed or photographed Leroy symbols (the same size as the television symbols resolved by 10 lines) when displayed on a screen whose size is comparable to that of the television monitor used in the present study. Figure 7 was constructed in the same way as that for televised symbols in Figure 5 (see text above). A comparison of Figures 5 and 7 shows that the total viewing area for the television display is only a small part of the total viewing area for good quality solid-stroke symbols of the same size.

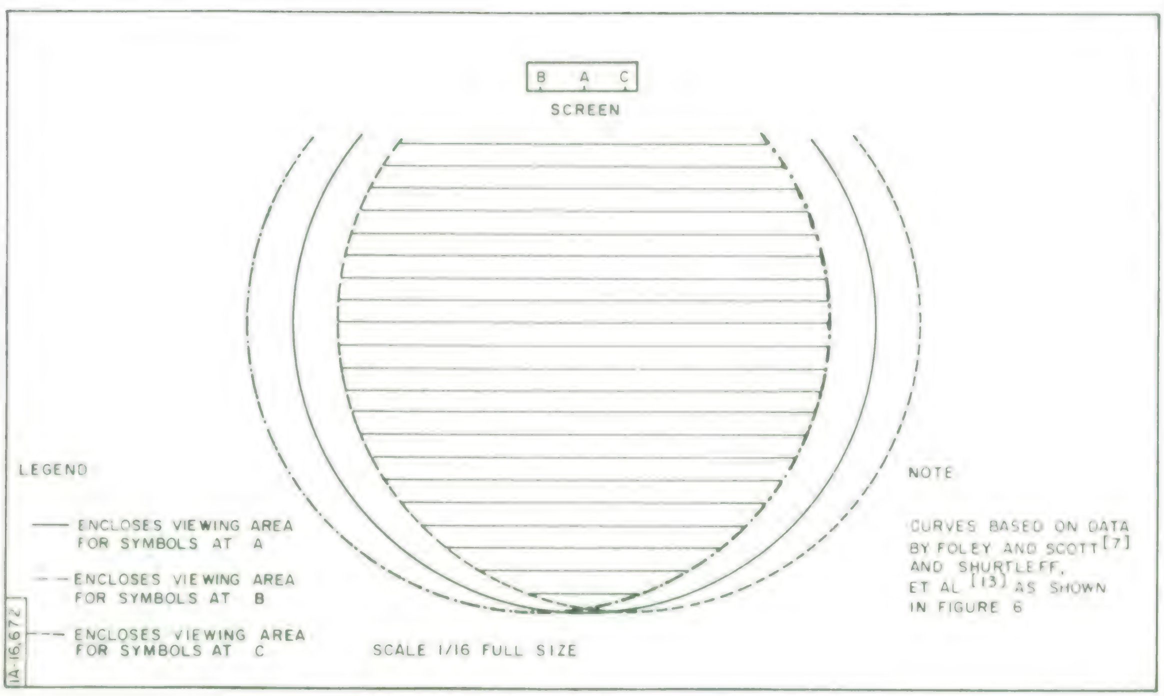

Figure 7. Viewing Areas for Printed or Photographed Symbols

SECTION VII

DISCUSSION OF VIEWING AREAS FOR TELEVISED SYMBOLS

RELATION OF VISUAL ANGLE TO RESOLUTION

The preceding analysis indicates that the angle of subtense required for good accuracy of identification (99-percent) for symbols resolved by 6 TV lines is so large as to require the subject to sit less than 10 inches from the monitor. At this distance many people would have trouble focussing their eyes, and those that could focus at this distance would soon complain of fatigue because of the extreme effort required to maintain a sharp image. Therefore, with the television displays of the present study, a symbol resolution of 8 lines is clearly the minimal acceptable resolution. However, even with 8 lines, the usable area of viewing is marginal for most applied situations since it places a severe restriction on the operator's freedom of movement. A symbol resolution of 10 lines, on the other hand, would give the operator more freedom of movement about the display without danger of his finding himself in a position of viewing where some symbols on the raster would be difficult to identify.

VIEWING AREA FOR A 945-LINE TV SYSTEM

Since the calculations of effective areas of viewing televised symbols are based upon data derived from a single television system, it might be asked how these calculations apply to other television systems. The data of this study have been used to plot the viewing area for a good quality 945-line television system. While minor variations in the area of viewing would be expected when other equipment of the same type is used, gross variations would not be expected. [4,7] Therefore, a conservative use of the present

calculations, say by reducing the viewing distances (for angles from 90 degrees to 15 degrees) by five percent (to take into account possible variations in equipment), and a further reduction of these viewing distances by 10 percent (to take into account subject differences*) should give one some confidence that the area outlined is one in which observers with 20/20 vision or better can identify symbols with minimal error. If a more precise determination of the usable area of viewing is required, the procedure used in this paper may be employed for the particular television system of interest.

VIEWING AREAS FOR VARIOUS SIZES OF PICTURE TUBES

Viewing areas for television monitors with picture tubes of different size** can be estimated by converting the distances shown in Figures 4 or 6 to visual angles. Given the height of the symbols on the monitor of interest and the visual angles required for different angles of viewing, it is a simple matter to determine the appropriate viewing distances by use of the formula $d = h/\tan\theta$, where d is the distance in inches, h is the height of the symbol in inches, and $\tan\theta$ is the tangent of the angle subtended by the symbol height. The distances should be corrected for equipment and subject variation in the same way as above, namely, by being reduced about 15 percent.

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* The required viewing distance for the worst subject in the group who saw a symbol resolution of 10 lines was 10 percent less than that of the mean distance for the group.

** The height of symbols resolved by a given number of scan lines will vary with the size of the picture tube. Also, for a given size of picture tube, slight variations in symbol height will occur because of differences in the size of the scanning spot.

HIGH QUALITY PRINTED AND TELEVISED SYMBOLS COMPARED

For example, when the analysis just described is used for the TV system of the present study, one finds that the angle of subtense is approximately 17.5 minutes of arc for a 90-degree viewing angle, a symbol resolution of 8 lines and symbols displayed at the center of the raster. This angle of subtense needs to be increased 15-percent (to take into account equipment and subject variations) to approximately 20 minutes of arc, which means a decrease in viewing distance on the 90-degree axis from 31 inches to approximately 25 inches. It is worthwhile to compare the angle of subtense just calculated for 8 lines to that recommended by Moore and Nida[8] for TV displays used in the Spanrad System. They recommended an angle of subtense of 9 minutes of arc for symbol resolutions of 8 to 9 lines. The recommendations for the Spanrad display were based upon the ability of subjects to read letters on a "standard eye test chart." The results of the present study indicate that the visual angle required for the reading of high quality printed symbols should not be used to estimate the visual angle required for identifying televised symbols of the same size. In fact, the present results indicate that the angle of subtense for TV symbols with a resolution of 8 to 10 lines needs to be at least twice that of high quality, printed symbols of the same size.

RESOLUTION REQUIRED FOR MAXIMUM IDENTIFICATION RATE

The viewing areas discussed so far represent areas in which 99-percent identification accuracy may be expected. However, if maximum rates of symbol identification are required, in addition to high accuracy, the viewing distances for 99-percent accuracy (Figure 4) would have to be shortened 34 to 43-percent according to the results of the first part of the experiment.

With such a large decrease in viewing distances, the viewing areas plotted in Figure 4 would be severely constricted even for symbols resolved by 10 television scan lines. Therefore, to meet a system requirement for maximum rate of symbol identification, a symbol resolution of 12 to 15 lines would probably be needed.

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13. ABSTRACT

An investigation was made to determine the visual sizes required for the identification of standard and revised Leroy alphanumerics, which were televised at resolutions of 10, 8, and 6 lines per symbol height. The visual size needed for 99-percent identification accuracy was similar for resolutions of 10 and 8 lines, but a significantly larger visual size was required for symbols resolved by 6 lines. There were no significant differences in visual sizes required for identification of standard versus revised Leroy symbols at any value of resolution. The findings were used to calculate the effective area for viewing televised symbols.

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